

Assessment of the plastic flows in The Netherlands using STREAMS

L.A.J. Joosten ^{a,*}, M.P. Hekkert ^a, E. Worrell ^b

^a *Department of Science, Technology and Society, Utrecht University, Padualaan 14,
NL-3584 CH Utrecht, The Netherlands*

^b *Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory,
1 Cyclotron Road, Berkeley, CA 94720, USA*

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Abstract

The STREAMS method, a method for material flow analysis based on national supply and use tables, is examined in an assessment of the flows of plastics in The Netherlands, for the reference year 1990. The method proves to be a powerful tool to get a total overview of plastic flows in The Netherlands. Using the method, it is possible to obtain a highly detailed view on the final consumption of materials, for which hitherto only highly aggregated estimates were available. With the STREAMS method, total final plastics consumption in The Netherlands in the year 1990 is calculated at 1260 kt, which fairly matches other estimates in literature. The STREAMS method also provides information on the final consumption of plastics on lower aggregation levels, e.g. the final consumption of plastics divided between industry sectors, split up between packaging, components and final products. Our calculations show that with regard to plastics in The Netherlands, apparent consumption, calculated as raw materials production plus imports minus exports, although easily calculable, is a rather poor approximation for final consumption. Several issues that affect the accuracy of the results of the STREAMS method are discussed and estimates are made of their contributions to the mean deviation of the results. Total mean deviation is calculated at $\pm 30\%$ for results presented on lower aggregation levels. On higher aggregation levels the accuracy of the results is much higher. © 2000 Elsevier Science B.V. All rights reserved.

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* Corresponding author. Tel.: +31-30-2537600; fax: +31-30-2537601.

E-mail address: l.a.j.joosten@chem.uu.nl (L.A.J. Joosten).

1. Introduction

Material Flow Analysis is a tool for getting insights into the volumes and characteristics of material flows through the economy. To reach a more sustainable materials consumption pattern a good understanding of current material flows is a prerequisite.

In The Netherlands, several institutes and organisations regularly publish information about material flows through the economy. Statistics Netherlands (CBS) publishes data on materials used by various industries, as well as data on foreign trade. Waste flows are analysed by the National Institute of Public Health and Environmental Protection (RIVM). Branch organisations provide information on several more specific material flows. With regard to plastics the Dutch Federation for Plastics (NFK) and the Association of Plastics Manufacturers in Europe (APME) publish data. Apart from these, various figures for specific flows are mentioned in other publications. However, in these publications a lot of different definitions, subdivisions and reference years are used, making it very difficult to combine data from different studies to obtain a complete picture of material flows through the economy.

Another problem is that, in literature, data on the *final consumption* of materials and products is very hard to find. In general only direct¹ supplies and purchases are mapped. However, goods that are purchased by industries are either used as final products, or as packaging, or as components. In the latter two cases the purchasing industry is not the final consumer. Packaging and components become part of the products of the industry. Together with these products the packaging and components reach the final consumer of those products. *He* is considered as the final consumer of the packaging and components as well.

In a previous article [1] we described the STREAMS method we developed to map material flows through society, based on the country's supply and use tables. As the STREAMS method only uses the country's supply and use tables as data source, no dissimilarities in definitions, subdivisions and reference years are to be expected. Depending on the level of detail of the supply and use tables, the results of the method can be highly detailed. Using the STREAMS method it is possible to assess material flows through society 'from cradle to grave'. It includes a calculation method for the stage of *final consumption*, in which all goods, including packaging and components, are assigned to the final consumer.

In this article, the STREAMS method is tested in a case study on plastic flows through The Netherlands in the year 1990. The objective is to obtain detailed and complete information on the volumes of plastic flows through all stages, from cradle to grave. First, in Section 2, an outline of the STREAMS method is given. Subsequently, the application of the method to the plastic flows in The Netherlands

¹ In our terminology 'direct' uses refer to uses of materials and products that can be read directly from statistics: one industry or consumer buys certain goods from another. Indirectly used are the materials embodied in product flows, e.g. packaging materials and components that come together with those goods.

is described stepwise in Section 3. The applicability of the method, the results and their reliability are discussed in Section 4. Finally, in Section 5, conclusions are drawn.

2. The STREAMS method

In this section the STREAMS method is summarised. For a comprehensive description we refer to our previous article [1].

The STREAMS method consists of two parts: the supply and use analysis and the final consumption analysis. In the supply and use analysis, data on the direct supply and use of the materials under investigation are subtracted from the supply and use tables. In the final consumption analysis, these data are used to calculate the final consumption of materials and products. It focuses on packaging and components, which are followed from the industries that use them to the final consumers of the products they are applied to.

The *supply and use analysis* contains the following steps:

First a *process scheme* of the material under investigation is constructed and core materials, core products and core industries are assigned. Those are the materials, products and industries that play a major role within the materials system under investigation. From the supply and use tables, the rows concerning core materials and core products are selected, from which a *core supply table* and a *core use table* are obtained. These monetary tables are corrected for confidential trade, converted into physical units and corrected for intrasectoral trade. Finally, the core materials content of core products is calculated.

If the core supply and use tables are sufficiently detailed, it is possible to read from them the direct use and supply of core raw materials, core intermediate materials, core products and core waste materials. These data are used in the *final consumption analysis* to calculate the final consumption of core materials and products.

The *final consumption analysis* contains the following steps:

All uses of goods from the core supply and use tables by industries are evaluated and the purpose of use is estimated. By this procedure a division is made between uses as final products, as components and as packaging. Subsequently, each industry's uses of packaging and components are allocated to the products of that industry. This way the products get packaging and components contents. Finally, these packaging and components are allocated to the users of the products in question.

3. Application of the STREAMS method to plastic flows in The Netherlands

In this section, the STREAMS method is applied to the flows of plastics in The Netherlands in 1990. The calculations start from the supply and use tables provided by Statistics Netherlands [2].² These tables are composed as shown in Fig. 1.

² In the publication indicated, tables were aggregated in order to get a surveyable presentation. However, in our calculations the original non-aggregated tables were used.

Together they present a total description of The Netherlands' economy in terms of the supply and use of 529 goods and 114 services by 123 industries, 104 service sectors and 10 'final demand categories'³, as well as imports and exports. All figures are expressed in monetary units and concern the year 1990.

3.1. The supply and use analysis

In the supply and use analysis, the direct use and supply of plastic materials and products are assessed.

3.1.1. Stepwise description of the supply and use analysis

In this section, the application of the supply and use analysis to the flows of plastics in The Netherlands in 1990 is described stepwise.

3.1.1.1. Construction of the process scheme of plastics and assignment of core materials, core products and core industries. The process scheme of plastics is shown in Fig. 2. Materials enter the scheme as feedstocks, which are processed into primary plastics, mostly in the form of granulates. Primary plastics are processed into plastic products, part of which are final products that are ready for final consumption. Plastic packaging and components, however, need a packing and assembling operation, respectively before reaching the final consumer. After some time of use, plastic products are discarded as post consumer plastic waste. Part of the post consumer plastic waste is recycled and used as secondary raw material

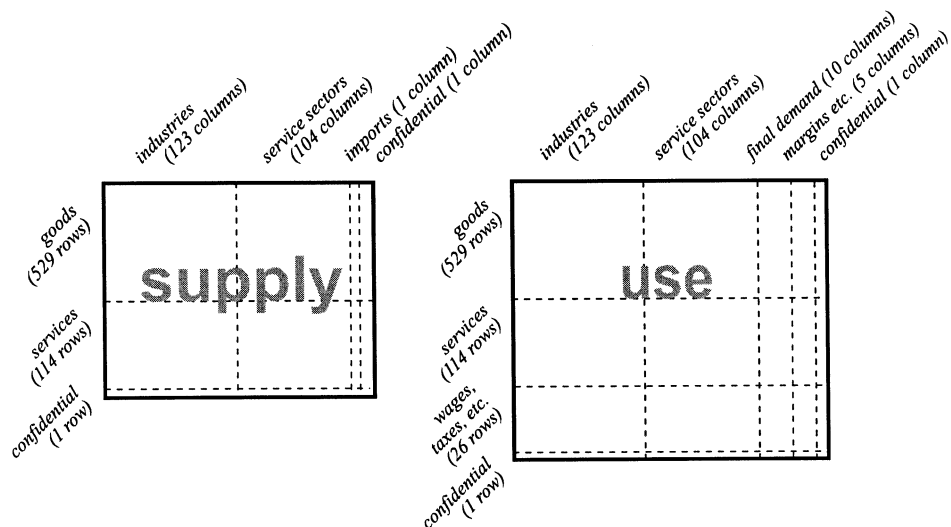


Fig. 1. Supply and use tables for The Netherlands.

³ Households, government, exports, investments, stock increase.

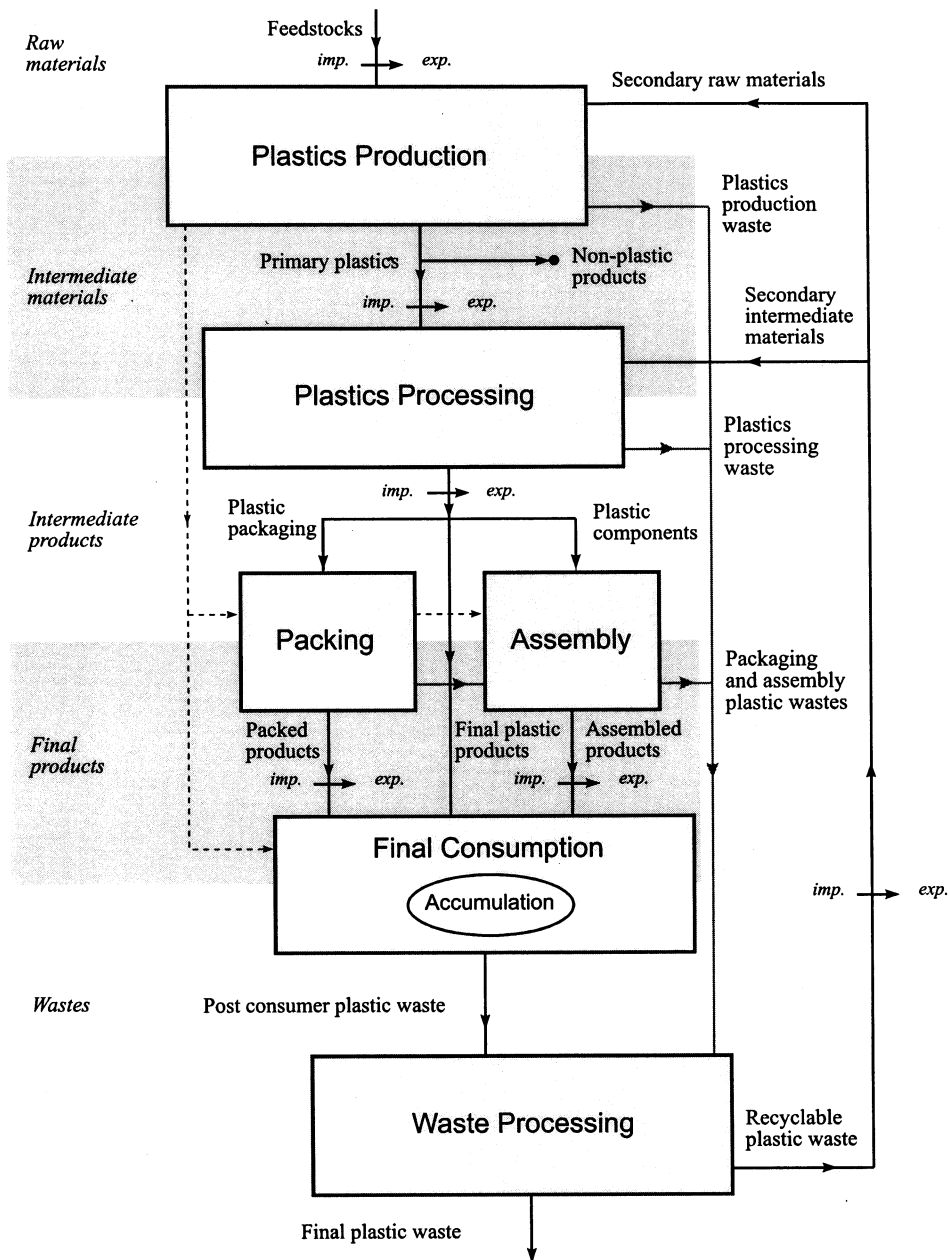


Fig. 2. Scheme of plastic flows through the economy.

(feedstock recycling)⁴ or secondary intermediate material (mechanical recycling). Also a part of the production, processing, packaging and assembly wastes, arising in the various processing steps, is recycled. The remainder of the plastic wastes, called final plastic wastes, is incinerated or landfilled.

For the investigation of plastic flows, the supply and use tables of The Netherlands contain data on a number of relevant materials and products, which we call *core* materials and products. They are listed in Table 1. One row in the supply and use tables concerns ‘primary plastics’, which represents all plastic intermediate materials (Fig. 2). Furthermore, 15 plastic products are discerned. Finally, there is one row representing plastic wastes.

Plastics are produced from fossil feedstocks. Although these feedstocks are discerned in the supply and use tables, it is impossible to make out which part is used for plastics production, because they are used to produce a whole range of commodities, of which plastics only form a part. Waste figures in the supply and use tables only concern wastes that are traded. Because the major part of post consumer plastic waste is not traded, figures from the supply and use tables about plastic wastes are incomplete and therefore unusable for the analysis.

In the supply and use tables, the producers of primary plastics fall into the categories ‘industry of synthetic resins’ and ‘other chemical industries’. Primary

Table 1

Plastic materials and products discerned in the Netherlands supply and use tables

Primary plastics

Plastic products

Plastic building materials^a

Plastic industrial components

Plastic films and sheets, cellular

Plastic films and sheets, reinforced

Plastic films and sheets, others

Plastic tubes

Plastic rods and profiles

Plastic floor covering

Plastic furniture

Plastic lighting

Plastic packaging^{b,c}

Refuse bags

Adhesive tape

Plastic office and school supplies

Other plastic products^d

Plastic wastes

^a Excluding plastic products of the other product categories used in building.

^b Including durable plastic packaging, like pallets, crates and containers.

^c Excluding plastic products of the other product categories used as packaging material.

^d Plastic footwear and clothing, brushes, combs, tailor’s dummies, etc.

⁴ In the reference-year 1990, this process was not yet used in The Netherlands.

Table 2

Supply and use of primary plastics and plastic products in 1990, as read from The Netherlands' supply and use tables

	Primary plastics		Plastic products ^a	
	Supply (mil. Dfl.)	Use (mil. Dfl.)	Supply (mil. Dfl.)	Use (mil. Dfl.)
Industry of synthetic resins	0	333	0	67
Other chemical industries	5961	204	9	205
Plastics processing industry	106	2346	5955	895
Other industries, service sectors and consumers	61	1451	508	9837
Confidential	3774	0	2301	0
Margins ^b	–	– 786	–	– 1891
Imports/exports	3820	10 174	6064	5724
Total	13 722	13 722	14 837	14 837

^a Aggregated.

^b Trade and transportation margins and product related taxes and subsidies.

plastics are largely processed into plastic products by the 'plastics processing industry'. But also other industries use primary plastics. Firstly, there are some industries of which the processing of primary plastics into plastic products forms only a minor activity. Secondly, primary plastics are used to produce *non-plastic products* like synthetic fibres, coatings, glues, etc., which are not rated among the plastic products. Non-plastic products are not considered in this analysis.

As can be seen from Fig. 2, direct information from the supply and use tables mainly concerns the 'intermediate materials' and 'intermediate products' stages.

3.1.1.2. Construction of the plastics supply and use tables. In the second step the rows representing the uses of primary plastics and plastic products are selected from the use table and ordered to form the plastics use table. This table shows the uses of primary plastics and plastic products by individual industries, service sectors and final demand categories, expressed in monetary units. Similarly, a plastics supply table is composed out of the supply table, representing the supplies of primary plastics and plastic products. In Table 2 the aggregated supplies and uses of primary plastics and plastic products by the main industries, as derived from the plastic supply and use tables, are presented.^{5,6}

⁵ 1 Dfl \approx 0.55 US\$ \approx 0.43 ECU (1990).

⁶ The tables in this report were aggregated in order to obtain a surveyable output. For the calculations, however, the original, full dimension tables are used.

3.1.1.3. Correction for confidential supplies. From Table 2 it is obvious that a considerable part of the supplies of primary plastics and plastic products is confidential. In the supply table confidential supplies are collected in a column ‘confidential’, which shows per product the amount of confidential supplies by the total Netherlands industry. There is also a row showing the total amount of confidential supplies per industry (Fig. 1).

Table 2 shows that, in the year 1990, 3774 million Dfl. of *primary plastics* supplies were confidential. On the other hand, according to the supply table, the total confidential supplies of the industry of synthetic resins amounted to 4198 million Dfl. The supply table shows no supply of primary plastics by the industry of synthetic resins (Table 2), whereas in fact primary plastics are the characteristic products of this industry. Therefore we assume that the confidential primary plastics supplies were in fact supplies by the industry of synthetic resins.

In 1990, the confidential supply of *plastic products* amounted to 2301 million Dfl (Table 2), whereas the confidential products supplies by the plastics processing industry amounted to 1818 million Dfl (supply table). We assume that the latter entirely consists of plastic products. Therefore 80% (1818/2301) of the confidential supplies of plastic products was added to the supply of the plastics processing industry.

As can be seen from Table 2, confidential *uses* of plastic materials and products play no role. The aggregated results of the correction are shown in Table 3.

3.1.1.4. Conversion of the monetary plastics supply and use tables into their physical equivalents. For the analysis of material flows, data expressed in physical units are needed. Therefore the plastics supply and use tables have to be converted from monetary units into physical units. In this analysis this is done relatively roughly,

Table 3

Supply and use of primary plastics and plastic products in The Netherlands in 1990, corrected for confidential trade

	Primary plastics		Plastic products	
	Supply (mil. Dfl.)	Use (mil. Dfl.)	Supply (mil. Dfl.)	Use (mil. Dfl.)
Industry of synthetic resins	3774	333	0	67
Other chemical industries	5961	204	9	205
Plastics processing industry	106	2346	7773	895
Other industries, service sectors and consumers	61	1451	508	9837
Confidential	0	0	483	0
Margins	–	–786	–	–1891
Imports/exports	3820	10 174	6064	5724
Total	13 722	13 722	14 837	14 837

Table 4
Supply and use of primary plastics and plastic products in The Netherlands in 1990; conversion from monetary units into physical units

	Supply (mil. Dfl.)	Price (Dfl./kg)	Supply (kt)	Use (mil. Dfl.)	Price (Dfl./kg)	Use (kt)
<i>Primary plastics</i>	9902	2.65	3733	4334	2.80	1546
<i>Plastic products</i>						
Plastic building materials	851	12.85	66	914	14.86	62
Plastic industrial components	613	16.39	37	810	17.46	46
Plastic films and sheets, cellular	319	7.99	40	260	8.49	31
Plastic films and sheets, reinforced	165	7.11	23	199	7.84	25
Plastic films and sheets, others	1347	5.52	244	1649	5.91	279
Plastic tubes	822	6.75	122	862	7.47	115
Plastic rods and profiles	360	7.80	46	373	8.43	44
Plastic floor covering ^a	267	4.46	60	308	5.78	53
Plastic furniture	277	6.49	43	271	7.49	36
Plastic lighting	14	18.47	1	89	22.52	4
Plastic packaging	1932	5.78	334	2601	6.41	406
Refuse bags	81	3.43	24	135	5.72	24
Adhesive tape	109	7.91	14	187	9.86	19
Plastic office and school supplies	147	10.05	15	231	12.00	19
Other plastic products	1469	8.66	170	2115	10.20	207
<i>Plastic products, total</i>	8773		1238	11 004		1371

^a Mean use price: 13.01 [Dfl./m²]; converted into [Dfl./kg] using the average weight of polyamide consumer carpets = 2.25 [kg/m²] which comprise the majority of this product category [4].

Table 5

Supply and use of primary plastics and plastic products in The Netherlands in 1990, corrected for confidential trade and converted into physical units

	Primary plastics		Plastic products	
	Supply (kt)	Use (kt)	Supply (kt)	Use (kt)
Industry of synthetic resins	1423	119	0	11
Other chemical industries	2247	73	1	30
Plastics processing industry	40	837	1098	127
Other industries, service sectors and consumers	23	517	59	1203
Confidential	0	0	80	0
Imports/exports	1440	3628	871	738
Total	5174	5174	2108	2108

using a mean price for each plastic material or product, regardless of the using industry. Mean prices are calculated on the basis of the CBS statistics of foreign trade [3]. These statistics are expressed in physical as well as in monetary units, making it possible to calculate mean export prices. We assume that mean prices on the domestic market do not differ considerably from mean export prices. Therefore we use exports prices for both international and domestic transactions. Physical plastics supply and use tables are obtained by dividing the monetary plastics supply and use tables by the mean exports prices for the various plastic materials and products.⁷ The conversion is shown in Table 4, whereas Table 5 shows the aggregated results of this step.

3.1.1.5. Correction for intrasectoral trade. From Table 5 it can be concluded that intrasectoral trade plays a role: industries sell certain amounts of their input materials and buy certain amounts of their output products. Further calculations call for a correction of this fact. In our approach mutual trade within industries is corrected for by calculating per industry the net use of input materials and the net supply of output products. The aggregated results of this correction are shown in Table 6.

3.1.1.6. Calculation of the primary plastics content of plastic products. With the data from Table 6, a mass balance analysis of the plastics processing industry is made. Table 6 shows that the plastics processing industry used 797 kt of primary plastics, whereas the total supply of plastic products by this industry amounted to 972 kt. Comparing the outputs with the inputs, and taking into account 42 kt of plastic

⁷ Due to trade and transportation margins, taxes and subsidies (collected in the column 'margins'), supply prices differ from use prices (like exports). This difference is taken into account by using a correction factor to the supply prices, calculated as the quotient of the total use including and excluding margins.

waste arising from this industry (as discussed later in this section), it becomes clear that plastic products do not entirely consist of primary plastics. In fact they contain all kinds of additives. Furthermore, products like plastic lighting are composed of several parts, some of which are not made of plastics. Also, plastic products may contain secondary (recycled) plastics, which are not included in the 797 kt of primary plastics used. The mass balance shows that on average 78% of plastic products consists of primary plastics. Therefore all figures in the physical plastic supply and use tables concerning plastic products were multiplied by this percentage in order to calculate the amount of primary plastics incorporated. Consequently, henceforward all figures concerning plastic products refer to their primary plastics content. Table 7 shows the aggregated results of the conversion into primary plastics content.

Table 6

Supply and use of primary plastics and plastic products in The Netherlands in 1990, corrected for confidential trade and intrasectoral trade

	Primary plastics		Plastic products	
	Supply (kt)	Use (kt)	Supply (kt)	Use (kt)
Industry of synthetic resins	1304	0	0	11
Other chemical industries	2175	0	1	30
Plastics processing industry	0	797	972	0
Other industries, service sectors and consumers	23	517	59	1203
Confidential	0	0	80	0
Imports/exports	1440	3628	871	738
Total	4942	4942	1982	1982

Table 7

Supply and use of primary plastics and plastic products in The Netherlands in 1990, corrected for confidential trade, intrasectoral trade and primary plastics content

	Primary plastics		Plastic products	
	Supply (kt)	Use (kt)	Supply (kt)	Use (kt)
Industry of synthetic resins	1304	0	0	8
Other chemical industries	2175	0	1	23
Plastics processing industry	0	797	755	0
Other industries, service sectors and consumers	23	517	46	934
Confidential	0	0	62	0
Imports/exports	1440	3628	676	573
Total	4942	4942	1539	1539

Table 8

Plastic wastes and mechanical recycling in The Netherlands in 1990

	Total (kt)	Mechanical recycling (kt) ^d
<i>Post consumer waste</i> ^a	781	87
<i>Production and processing wastes</i> ^b		
Chemical industry	40	15
Plastics processing industry	42	31
Other industries ^c	41	23
<i>Production and processing wastes, total</i>	123	69
Total	904	156

^a Ref. [6].^b Ref. [5].^c Industrial plastic waste from producing plastic products by 'other industries' plus plastic packaging and assembly waste.^d Including internal recycling.

3.1.2. Plastic wastes

Two types of plastic wastes are discerned: firstly post consumer plastic waste, consisting of the waste from final consumption and secondly industrial plastic waste, consisting of material losses from the production, processing and assembly of plastics and plastic products, as well as plastic packaging waste arising from packing products.

As the data on plastic wastes in the supply and use tables are incomplete and therefore not usable for the analysis, other data sources are also explored. According to the APME [5] post consumer plastic wastes in The Netherlands in 1990 amounted to 781 kt; 87 kt of these were mechanically recycled, 265 kt were incinerated and 429 kt were disposed of by landfilling. From an inquiry into industrial wastes by Statistics Netherlands [6], it is concluded that plastic production wastes in the chemical industry in 1990 amounted to 40 kt, whereas the total plastic wastes from plastics processing amounted to 83 kt. An overview of The Netherlands' plastic wastes is presented in Table 8.

3.1.3. Results of the supply and use analysis

The calculations described above result in detailed physical plastic supply and use tables, in which the direct supply and use of primary plastics and 15 plastic products by 237 industries, service sectors and consumers is described. Using these tables the material flows in the first stages of the life-cycle (the upper part of Fig. 2) can be quantified. The results are shown in Fig. 3.

3.2. The final consumption analysis

Above, only *direct* supplies and uses of primary plastics and plastic products were determined. However, a lot of plastic products are used indirectly: they serve as packaging or as components for other goods and change hands once more before

reaching the final consumer, together with those goods. In order to follow packaging and components to their final consumer, we developed the final consumption analysis. In this analysis plastic packaging and components used by industries are allocated to their products, and subsequently to the users of those products.

3.2.1. Stepwise description of the final consumption analysis

In this section we stepwise describe the application of the final consumption analysis to the flow of plastics through The Netherlands in 1990.

3.2.1.1. Evaluation of the purpose of use of primary plastics and plastic products.

From the plastics processing stage, plastics follow different routes through the process scheme. In the following calculations this has to be taken into account. From Fig. 2 it can be seen that plastic products are used for three different purposes: as final products, as packaging or as components. Primary plastics are used to produce plastic products or non-plastic products. However, because some industries use primary plastics to produce packaging, components or final products for their own use, also the three purposes of use for plastic products are applied to primary plastics. In Fig. 2 these primary plastics follow the dotted lines (see also

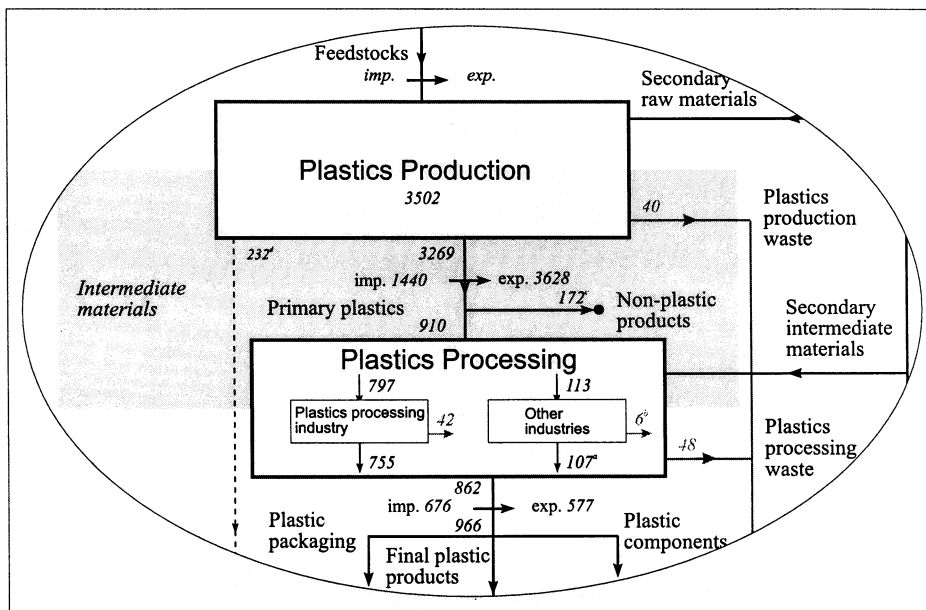


Fig. 3. Aggregated results of the supply and use analysis. ^aIncluding 62 kt of confidential supplies. ^bPlastic processing waste from 'other industries' was calculated using the same waste percentage (6.4%) as the plastics processing industry. ^cPrimary plastics use for producing non-plastic products consists of the use of primary plastics by the industries of textiles, pigments, paint, ink, detergents and glues. ^dPrimary plastics used to produce packaging, components and final products which are not further traded, but which are used in the producing industry itself.

Table 9

Purposes of use of primary plastics and plastic products

Purpose of use	Primary plastics	Plastic products
Production of plastic products	×	
Production of non-plastic products	×	
Use as packaging	×	×
Use as components	×	×
Use as final products	×	×

Ref. [1]). Table 9 summarises the different purposes of use of primary plastics and plastic products.

In our approach the use of primary plastics and plastic products by each industry is examined and the purpose of use is estimated. We assume all purchases of primary plastics and plastic products by service sectors and final demand categories to be final consumption, because these sectors do not hand over many products.⁸

From Table 7 it can be seen that, after the corrections, 60 kt of confidential supplies of plastic products still remain. Because it is not visible which industries are the suppliers of those products, it is impossible to see which industries use primary plastics to produce them. We only know that it is *not* the plastics processing industry. However, for further calculations it is important to assign the uses of primary plastics for producing plastic products, in order to avoid double counting. We use an alternative method to assign primary plastic use for producing plastic products by 'industries other than the plastics processing industry. First we assign the primary plastic use by these 'other industries' to the four other categories (Table 9), neglecting 'use for producing plastic products'. The result of this is that the 113 kt of primary plastics use by industries other than the plastics processing industry (Fig. 3) that should be in this category, are assigned to 'use as packaging' and 'use as component' instead. So too much primary plastics are assigned to the latter two categories. Next these categories are adjusted by lowering all uses of primary plastic by other industries than the plastics processing industry with a percentage which reduces the total use by 113 kt.

The physical plastics use table is split into five plastics use tables, one for each purpose of use (as distinguished in Table 9). The totals of the plastic use tables concerning 'use as final product', 'use as packaging' and 'use as component' can be read from Table 10.

3.2.1.2. Construction of the goods supply and use tables. From the original supply and use tables, which contain both goods and services, the rows referring to the supply and use of services are removed, because the deliverance of plastics is only connected to the deliverance of goods, not to the deliverance of services. What remains are the goods supply and use tables.

⁸ From the use and supply tables it is not possible to read the materials and products delivered by trade (a service sector), so primary plastics and plastic products used in trade cannot be assigned to the products supplied by this sector.

3.2.1.3. Construction of the percentage goods supply table. For each industry, all supplies of goods are divided by the total supply of goods by that industry, in order to form the percentage goods supply table.

3.2.1.4. Allocation of plastic packaging and components to goods supply. The percentage goods supply table is multiplied by the plastic use tables concerning ‘use as packaging’ and ‘use as component’. By this means, for each industry the primary plastics and plastic products used as packaging or as component are allocated to the goods supplied by that industry. The calculations result in 16 tables (one for primary plastics and 15 for plastic products) representing the assignment of primary plastics and plastic products used as packaging and another 16 tables representing the assignment of primary plastics and plastic products used as components.

3.2.1.5. Calculation of the plastic packaging and plastic component contents of goods. Generally, goods are supplied by more than one industry, as can be read from the supply and use tables. Because each industry has its own pattern of packaging and components use, amounts of packaging and components assigned to the same good supplied by different industries are not exactly equal. However, for further calcula-

Table 10

Purpose of use of primary plastics and plastic products; totals for The Netherlands in 1990

	Use as final products (kt)	Use as packaging (kt)	Use as components (kt)	Total use (kt)
<i>Primary plastics</i>	104	4	125	232
<i>Plastic products</i>				
Plastic building materials	41	0	6	47
Plastic industrial components	4	0	29	33
Plastic films and sheets, cellular	7	8	6	22
Plastic films and sheets, reinforced	10	0	8	18
Plastic films and sheets, others	19	109	26	153
Plastic tubes	56	0	21	77
Plastic rods and profiles	12	0	20	31
Plastic floor covering	41	0	0	41
Plastic furniture	28	0	0	28
Plastic lighting	3	0	0	3
Plastic packaging	109	203	0	313
Refuse bags	18	0	0	18
Adhesive tape	12	0	3	15
Plastic office and school supplies	15	0	0	15
Other plastic products	152	0	0	152
<i>Plastic products, total</i>	526	321	119	966

tions unambiguous plastic packaging and plastic component contents for each good are needed. This is achieved by dividing the total amount of primary plastics and plastic products assigned to each good by the total national supply of that good. By this means, average plastic contents of all goods are obtained, in which differences between industries are eliminated.

Again, confidential supplies cause a complication. Because in the calculation method primary plastics and plastic products used as packaging or components are assigned to *all* of the industry's supplied goods, also its *confidential* goods become a plastic content. It is, however, unknown which goods are involved. So it is also unknown which goods the packaging and components have to be assigned to. We solved the problem by using an alternative allocation method for those confidential goods. From the column 'confidential' in the supply table the total national amount of confidential supplies of each good is deduced. We divide the total amount of plastic packaging and components assigned to the confidential goods of all industries together proportionally between the total domestic supplies of these confidential goods.

3.2.1.6. Assignment of plastic packaging and components to the final consumers. By multiplying the use table of goods by the plastic contents obtained above, the primary plastics and plastic products used as packaging or as components are assigned to the final consumers. This results in two tables, representing the '*indirect final consumption*' of plastics, as packaging and components, respectively. Imports and exports of products are multiplied the same way by the plastics contents, in order to assess the *indirect* imports and exports of plastics. We assume that imported goods are comparable with respect to plastic packaging and component contents to goods manufactured domestically and that goods produced for exports are comparable to goods for the domestic market.

3.2.2. Results of the final consumption analysis

The aggregated results of the final consumption analysis are presented in Tables 11–14. Table 11 provides information on the final consumption of the primary plastics and plastic products divided between direct final consumption, indirect final consumption as packaging and indirect final consumption as components. Table 12 shows the direct and indirect final consumption of plastics by consumer groups. In Table 13 the indirect final plastics consumption is displayed, divided between the categories of goods they were applied to. Finally, Table 14 shows the indirect imports and exports of primary plastics and plastic products, used as packaging or as components.

With the results of the final consumption analysis, the scheme of plastic flows in The Netherlands (Fig. 3) can be completed. The result is shown in Fig. 4.

4. Discussion

In this section, the applicability of the STREAMS method is discussed. In Section 4.1 the usefulness of the use and supply tables of The Netherlands as data

Table 11

Direct and indirect final consumption of primary plastics and plastic products in The Netherlands in 1990

	Direct final consumption (kt)	Final consumptionas packaging (kt)	Final consumptionas components (kt)	Final consumption, total (kt)
<i>Primary plastics</i>	104	4	162	270
<i>Plastic products</i>				
Plastic building materials	41	0	9	49
Plastic industrial components	4	0	39	43
Plastic films and sheets, cellular	7	11	7	26
Plastic films and sheets, reinforced	10	0	11	20
Plastic films and sheets, others	19	119	30	168
Plastic tubes	56	0	26	81
Plastic rods and profiles	12	0	25	37
Plastic floor covering	41	0	0	41
Plastic furniture	28	0	0	28
Plastic lighting	3	0	0	3
Plastic packaging	109	185	0	294
Refuse bags	18	0	0	18
Adhesive tape	12	0	3	15
Plastic office and school supplies	15	0	0	15
Other plastic products	152	0	0	152
<i>Plastic products, total</i>	526	315	149	991
<i>Total</i>	630	319	312	1260

source for material flow analysis is discussed. The main results are discussed in Section 4.2. In Section 4.3 we attempt to validate the method by comparing its results to the results of other studies. Subsequently, in Section 4.4, we discuss a number of methodological aspects that may affect the accuracy of the results and estimate the contributions to the mean deviation of the results. Finally, in Section 4.5, the total mean deviation of the results is calculated.

4.1. Usefulness of The Netherlands' use and supply tables for material flow analysis

Because the STREAMS method starts from the country's supply and use tables,

the minimum aggregation level of the results depends on the aggregation levels of these tables. This applies to the goods, the core materials, the core products and the industries and consumers that are discerned. The supply and use tables of The Netherlands proved to be sufficiently detailed for the study of plastic flows: 237 different industries and consumers are discerned, using and supplying 529 different goods, 15 of which can be identified as plastic products. On the other hand, only one category 'primary plastics' is discerned, which contains all primary plastics. This makes it impossible to discriminate between primary plastic types (e.g. polyethylene, polypropylene). Although a category 'plastic waste' is discerned, it is not usable for the analysis because it only comprises plastic wastes that are traded and is, therefore, incomplete.

4.2. Results

From our calculations it follows that the total final consumption of plastics in The Netherlands in 1990 amounted to 1260 kt. Table 11 shows that 630 kt of these were consumed directly, as final product, 319 kt as packaging and 312 kt as components. Table 11 also says something about the route that was followed by the plastics till final consumption. Almost 80% of final plastics consumption appears in Table 11 as 'Plastic products'. These plastics were used by one industry to produce plastic products, which were subsequently sold to another industry that used them as final product, as packaging, or as components. The remaining 20%, which

Table 12
Direct and indirect final consumption of plastics in The Netherlands in 1990, by consuming sector

	Direct final consumption (kt)	Final consumption as packaging (kt)	Final consumption as components (kt)	Final consumption, total (kt)
Agriculture and fishing	3	6	1	11
Industry	54	105	101	260
Building	171	19	31	220
Trade	86	6	8	100
Other services ^{a1}	106	35	28	170
Households	97	112	72	281
Investments ^{b1}	82	31	64	176
Stock increase	31	5	7	42
Other final demand categories	0	0	0	1
Total	630	319	312	1260

^a Including catering, government, education, banking and health services.

^b Purchases of durable capital goods (lifetime 1 year or more).

Table 13

Indirect final consumption of plastics in The Netherlands in 1990, by product type

	Final consumption as packaging (kt)	Final consumption as components (kt)	Indirect final consumption, total (kt)
Food and smokers' requisites	96	1	97
Textiles and fashion articles	14	13	27
Paper and printers' articles	22	23	45
Building materials and interior	24	34	58
Energy carriers	4	4	8
Chemical products ^{a1}	54	10	65
Metal products and machinery ^{b1}	66	148	213
Means of transportation	19	38	57
Other products ^{c1}	19	41	60
Total	319	312	630

^a Including soaps, cosmetics and medicines.^b Including household appliances.^c Photographic materials, clocks, toys, camping equipment, sports equipment, etc.

Table 14

Indirect imports and exports of plastics as packaging or as components to and from The Netherlands in 1990

	Imports	Exports
As packaging	189	175
As components	248	165
Total	437	340

appear as 'primary plastics', are plastic products that were used as final product, as packaging material, or as components by the same industry as the industry that produced them from primary plastics. This means that these industries produced their own final products, packaging and components. As can be seen from Table 11, this is often the case with components: 52% of components were 'home made' by the industries that built them into their products. This is in contrast to packaging, of which only 1% was 'home made' by the industries that used them to

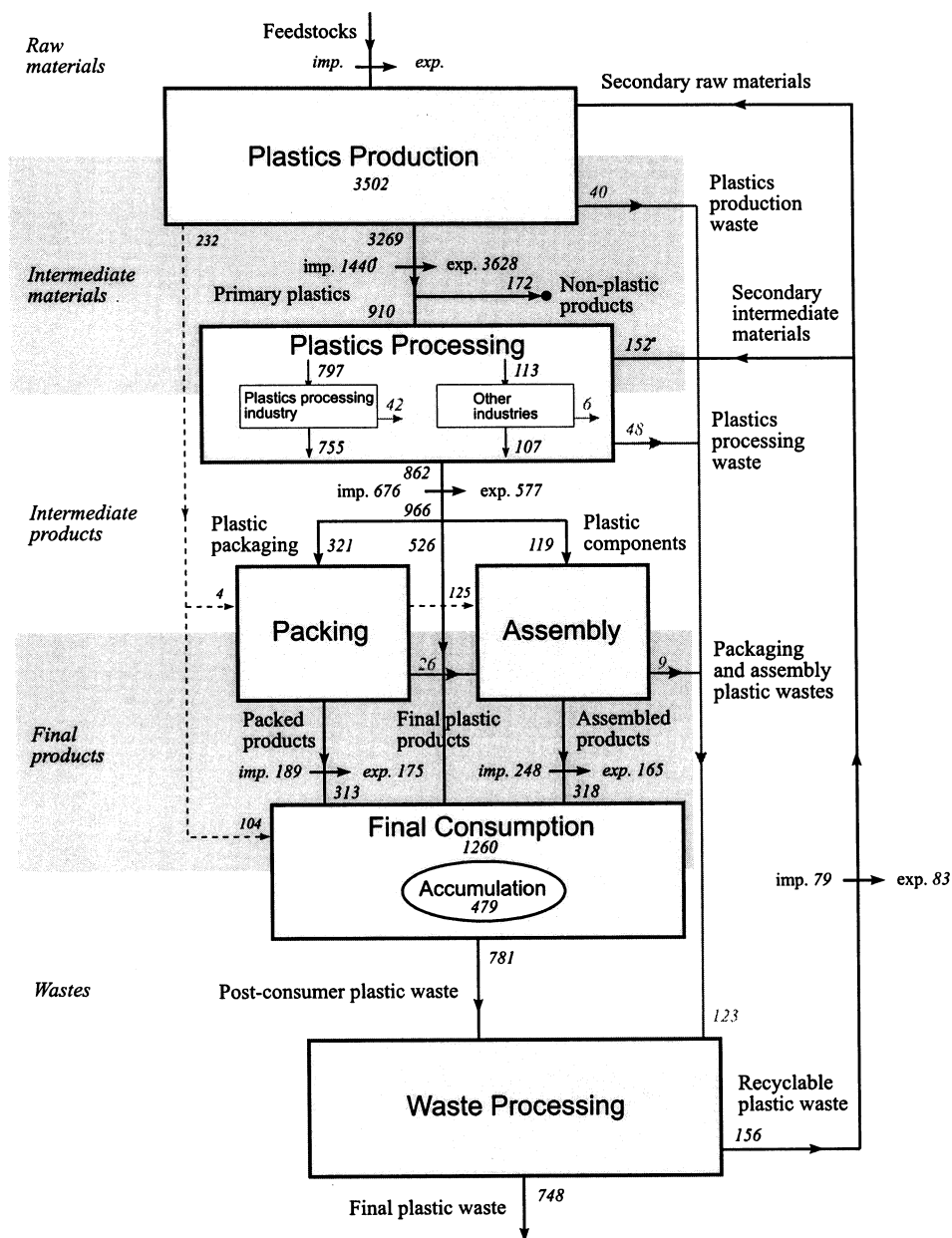


Fig. 4. Flow of plastics in The Netherlands in 1990 (kt), based on aggregated results obtained using the STREAMS method. All figures concern primary plastics content; secondary materials content is not included.

pack their products. So almost all plastic packaging is bought from other industries. The 104 kt of primary plastics in the column ‘Direct final consumption’ of Table 11 are primary plastics used by service sectors that do not sell products. From the physical plastics use table it can be derived that these encompass 56 kt of primary plastics (mainly PUR) used in building and 22 kt of primary plastics used in research.

According to Table 11 the direct final consumption of plastic packaging in The Netherlands in 1990 (plastic packaging used directly by service sectors and final demand categories) amounted to 109 kt. Table 11 also shows that the indirect final consumption of plastic packaging amounted to 319 kt. So the total final consumption of plastic packaging is calculated at 428 kt, which is 34% of total final plastics consumption. Components make up 25% of total final plastics consumption. The remaining 41% can be roughly divided into ‘consumer products’⁹: 18% and ‘building materials and others’: 23%.

Table 12 shows that the sector ‘households’ is the largest final consumer of plastics. The final plastics consumption of the sectors ‘building’ and ‘industry’ is also considerable. From Table 13 it can be seen that 30% of plastic packaging finally consumed in The Netherlands in 1990 was used to pack food and smokers’ requisites; 21% was used to pack metal products and machinery (including household appliances). It is not very surprising that a large part of components (47%) were also used for metal products and machinery.

4.3. Comparison with other studies

In order to get an idea of the accuracy of the results of a calculation method we can compare them to the results of similar studies. For several reasons comparison of our results to the results of other studies turns out to be very difficult. Firstly, in literature, studies on *final consumption* are almost completely lacking. ‘Final plastics consumption’ data in literature often refer to apparent consumption, calculated as the production of primary plastics plus imports of primary plastics minus exports of primary plastics. The results show that apparent plastics consumption (1142 kt excluding non-plastic products, see Fig. 4) differs considerably from final plastics consumption as calculated with the STREAMS method (1260 kt, see Table 11). The difference is mainly caused by differences between imports and exports. As can be seen from Fig. 4, direct imports of plastic products exceed exports of plastic products by 99 kt. Also indirect imports and exports differ. The difference between indirect imports and exports of plastic packaging is relatively small (15 kt), but the difference between indirect imports and exports of plastic components is considerable (87 kt). The latter is caused by the fact that The Netherlands houses a relatively small industry of machines and transportation equipment, so a considerable part of the equipment for production and transportation used in The Netherlands is imported. Another difference between apparent consumption and final

⁹ Furniture, lighting, refuse bags, adhesive tape, office and school supplies and other products.

consumption lies in the fact that in apparent consumption processing waste is included, whereas in final consumption it is not.

As a second problem in comparing the results of two or more studies, we face the fact that every study uses its own, often implicit definitions, subdivisions and reference years. The fact that there are many material flows through society, following a widespread network of routes, being used by many users for many purposes, adds to the confusion among authors, making literature hard to interpret correctly. In the case of plastics a number of factors forms a further complication. It makes a difference whether data concern plastics with or without additives, plastic products with or without non-plastic parts, plastic waste including or excluding dirt and water and ‘primary’ plastics with or without regranelite. Data sources that are obscure concerning these aspects are still harder to interpret. Because of these difficulties only total plastic packaging use can be compared to the results of other studies.¹⁰

The direct use of plastic packaging in The Netherlands in 1990 can be derived from Table 10. According to Table 11, 109 kt of plastic packaging were used as final product. Furthermore, 321 kt of other plastics were used as packaging by The Netherlands’ industry. So the total use of plastic packaging amounted to 430 kt. This figure comes close to the amount of $41\% \times 992 = 407$ kt of plastics used for packaging, as reported by the APME [5]. As stated above, total *final* consumption of plastic packaging amounted to 428 kt. Because this amount refers to a primary plastic content of plastic products of 78%, the total weight of plastic packaging that is finally consumed in The Netherlands in 1990 is calculated at about 550 kt. In literature, final consumption of plastic packaging in The Netherlands is estimated at 470 kt in the year 1988 [7,8]. The difference between our calculations and this estimate from literature is mainly accounted for by the growth of plastic consumption between 1988 and 1990. In this period, plastics consumption in The Netherlands has grown by 13% [9]. So the estimate of 470 kt in 1988 corresponds to about 530 kt in 1990. Our result of about 550 kt compares fairly to this estimate.

Other data in literature, which could be used to validate the model, are not available. Therefore, in the following sections we estimate the mean deviation of the results, based on a theoretical analysis of factors that may affect the accuracy of the results.

4.4. Factors affecting the accuracy of the results

In this section, we discuss the most important factors that affect the accuracy of the results obtained from application of the STREAMS method to plastic flows in The Netherlands. In addition, we give an estimate on the mean deviations they

¹⁰ In comparing the results of the STREAMS method to data in literature, one has to bear in mind that all results of the STREAMS method concerning plastic products refer to their primary plastics content. In the case of plastic flows in The Netherlands, we calculated an average primary plastics content of 78%. This percentage has to be accounted for, because data in literature generally concern the total weight (100%) of plastic products.

cause to the results. A general property of the results is that their accuracy is higher if presented on a higher aggregation level. Our estimates apply to the lowest aggregation level: individual plastic materials and products used as packaging or components for individual goods that are used by individual industries.

4.4.1. *The supply and use analysis*

The supply and use analysis contains two steps that may affect the accuracy of the results: the conversion of the plastics use and supply tables from monetary units to physical units and the calculation of the primary plastics content of plastic products.

4.4.1.1. Conversion of the plastics use and supply tables from monetary to physical units. As a rough approximation for the conversion of the monetary plastic use and supply tables into their physical equivalents, we used The Netherlands' statistics of foreign trade, which are expressed in monetary as well as in physical units. This makes it possible to calculate mean export prices per plastic material or product. Assuming that these prices do not differ significantly from mean prices on the domestic market, we applied them to all uses and supplies of plastic products. Statistics Netherlands has also made an effort to convert the monetary plastics use and supply tables into physical units, using a more sophisticated method, using different prices for each industry and balancing principles [10,11]. We used the results of this approach, published in an aggregated form, to validate our conversion method.

Comparison of the results of both conversion methods shows that the results, on a high aggregation level, e.g. the total use and supply of plastic products by all industries, are fairly matching. For the use and supply of all plastic materials and products together by individual industries we observed a mean deviation of $\pm 9\%$. For the use and supply of individual plastic materials and products by all industries together we observed a mean deviation of $\pm 5\%$. On lower aggregation levels some results are less promising. For the separate plastic products and for individual industries, the agreement differs. For the plastic product categories 'plastic packaging' and 'plastic films and sheets, others', the results are fairly corresponding (deviations $< 10\%$). Some other plastic product categories, like 'plastic building materials' and 'plastic industrial components', show deviations of up to 60%. There are two reasons for this: firstly the fact that the calculation of mean export prices is rather difficult because of mismatches between the plastic product categories discerned in the use and supply tables on the one hand and the product categories in the statistics of foreign trade on the other hand. The second reason is that in practice there may be differences between mean export prices and prices on the domestic market. Each product category consists of a range of products with different prices. Therefore it is possible that exported products have different prices as products of the same product category produced for the domestic market. For the use and supply of individual plastic materials and products by individual industries we observed a mean deviation of $\pm 19\%$.

4.4.1.2. Calculation of the primary plastics content of plastic products. We calculated a mean primary plastics content of plastic products of 78%,¹¹ the rest consists of additives, other materials and recycled plastics. We used this mean value to calculate the primary plastics content of all plastic products. By doing this, additives, other materials and recycled plastics were spread over all plastic products. In practice, however, plastic products contain different contents of additives, other materials and recycled plastics. We estimate that this causes a mean deviation of $\pm 10\%$.

4.4.2. The final consumption analysis

In the final consumption analysis, five possible sources of deviation can be discerned, which will be discussed in this section.

4.4.2.1. Evaluation of the purpose of use of plastic materials and products. We estimated the purpose of use of plastic materials and products based on common sense and general knowledge on industries and the goods they produce. Of course, mistakes are possible. We estimate the mean deviation caused by this issue at $\pm 10\%$.

4.4.2.2. Allocation of packaging and components to produced goods. In the STREAMS method, the allocation of core packaging and components is necessarily based on a monetary basis, because the —monetary— percentage goods supply table is used. In practice, however, packaging and components contents of goods are probably more closely related to weight than to economic value. Furthermore, because the method allocates packaging and components used by industries to *all* of their produced goods, on a minor scale some strange results are obtained, like living cattle packed in plastic, caused by the use of plastic packaging — for packing vegetables — in agriculture. We estimate the mean deviation caused in the allocation step at $\pm 15\%$.

4.4.2.3. Confidential supplies. The supply and use tables of The Netherlands contain relatively large omissions caused by confidentiality. In The Netherlands, 14% of all supplies are confidential. The reason for this is that The Netherlands is a small country with only one or a few companies in some industries, the sales of which are not published in national statistics. In STREAMS, this causes some complications. Firstly, because of the existence of confidential supplies of plastic materials and products in the supply and use tables, it is not possible to construct plastics supply and use tables without ‘guessing’ which industries are the suppliers. Secondly, because plastic packaging and components are allocated to all products of the industries that use them, also the industries’ confidential supplies become a plastic content. From the calculations it can be derived that 13% of the plastic packaging and 22% of the plastic components are allocated to confidential supplies. As it is

¹¹ If secondary plastics were included, this would be 96%.

unknown which goods are supplied confidentially per industry, it is also unknown which goods these packaging and components must be allocated to. For these goods we had to add an alternative calculation step to the STREAMS method. This step divides the total amount of plastic packaging and components that is allocated to the confidential supplies of all industries together between the confidentially supplied goods. We estimate that this issue causes a mean deviation of $\pm 10\%$. If the STREAMS method is applied to other, larger countries — with less confidential supplies — this deviation is expected to be much lower.

4.4.2.4. Calculation of the plastic contents of goods. In STREAMS, the calculation of plastic contents of goods is based on the supply and use tables, which are a representation of the national industry. Imported products are assumed to have the same composition and the same packaging content as domestically produced products. A result of this is that products that are not produced domestically, but which are fully imported, receive no plastic content. The results of our calculations show that in The Netherlands this is the case, for example, for refrigerators. For goods that are largely produced in The Netherlands this issue plays a lesser role. Because this issue plays a role for only a limited number of products, we expect a mean deviation of $\pm 5\%$.

4.4.2.5. Trade. In practice, trade is involved in many supplies and uses. The supply and use tables, however, do not state in which supplies and uses trade is involved. Therefore it is impossible to allocate plastic packaging and components used in trade to the products that are traded. Table 12 shows that 86 kt of plastics were used in trade. In the calculations they end up as final consumption in trade, whereas in reality a part of this amount ends up at the users of the products that are traded. On the other hand, industrial packaging like shrink films, which are used to bundle a number of products and which, in practice, end up in trade, are allocated to the users of the products traded. These two deviations partly neutralise each other. Because of this we estimate the mean deviation from this issue at $\pm 5\%$.

4.5. Estimate of the total mean deviation of the results

Several factors affecting the accuracy of the results were discussed above. All individual mean deviations add up to a total mean deviation. Because the calculations of the method mainly consist of multiplications, the total mean deviation is calculated with the formula:

$$D^2 = \sum_i d_i^2$$

where D is the total mean deviation and d_i , individual mean deviations.

This way the total mean deviation of the model results is calculated at $\pm 30\%$. This applies to the lowest aggregation level: individual plastic materials and products used as packaging or components for individual goods, which are finally consumed by individual consumers. Results presented on higher aggregation levels are much more accurate.

5. Conclusions

This study shows that the STREAMS method is a powerful tool for the analysis of a country's material flows. It demonstrates that highly detailed information can be obtained on materials flows in all stages of their lifecycle. The method is unique in studying the stage of final consumption, a stage that is largely neglected in literature, but which is the most accurate measure of a country's materials consumption. By applying the model to the flows of plastics in The Netherlands in 1990, we calculated the total final consumption of plastics in The Netherlands at 1260 kt. This is considerably higher than the apparent consumption of 1142 kt that is calculated rather roughly from the production, imports and exports of primary plastics. Therefore we conclude that apparent consumption, although easily calculable, is rather a poor approximation for final consumption.

However, the STREAMS method faces a number of problems that should be solved in order to get more accurate results. We estimate the mean deviation of the results of our analysis on the lowest aggregation level at $\pm 30\%$. Results presented on higher aggregation levels are much more accurate. Part of the deviation is caused by factors that are typical for the situation in The Netherlands, like the high amount of confidential supplies. Other factors are inherent to the method, for example the fact that the allocation takes place on a financial basis. A number of factors can be eliminated by refinement of the method. Notably, the conversion from monetary into physical units and the allocation step can be improved considerably, leading to more accurate results. These improvements will be implemented in the model in a following study, a case study on paper and wood flows in The Netherlands [12]. We expect that these refinements will diminish the mean deviation of the results on the lowest aggregation level to about $\pm 15\%$.

If the method is applied to other, larger economies, of which the statistics contain less omissions for confidentiality reasons, even smaller mean deviations are expected. On the other hand, if statistical data becomes less detailed, less detailed results are to be obtained. Provided that no major changes take place in statistical data collection and representation, the analysis may be repeated for subsequent years, in order to track changes in plastic uses over time.

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